

(19)



Europäisches Patentamt

European Patent Office

Office européen des brevets



(11)

**EP 1 011 182 A1**

(12)

## EUROPEAN PATENT APPLICATION

(43) Date of publication:  
**21.06.2000 Bulletin 2000/25**

(51) Int. Cl.<sup>7</sup>: **H02G 13/00, F03D 11/00**

(21) Application number: **98123733.2**

(22) Date of filing: **14.12.1998**

(84) Designated Contracting States:  
**AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU  
MC NL PT SE**  
Designated Extension States:  
**AL LT LV MK RO SI**

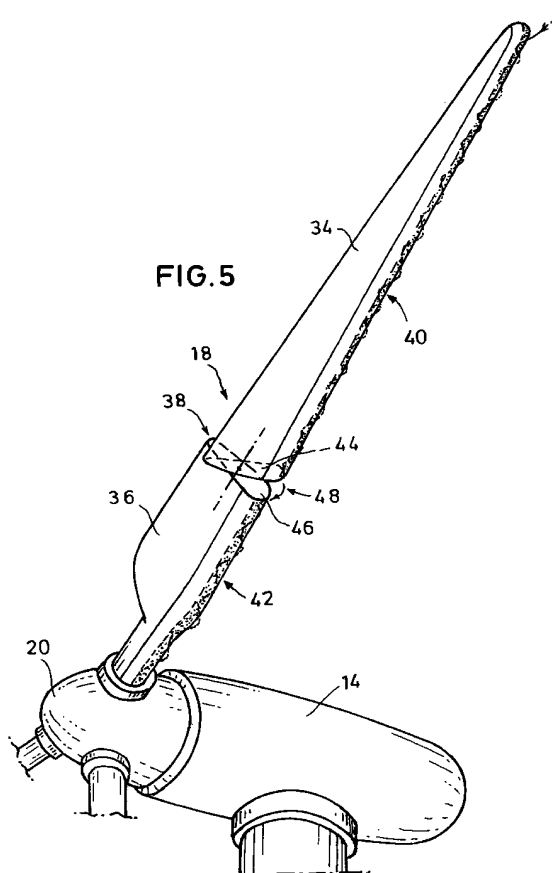
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### (54) Lightning protection apparatus for a longitudinal member

(57) The lightning protection apparatus for a longitudinal member (18) comprises an electrical conductor (28) arranged along the length of the member (18). Said conductor (28) is an electrically conductive layer (28) of a tape (22,22b) having also an adhesive layer (26,26b) for adhering said tape (22,22b) to the outer surface (32) of the longitudinal member (18) along the length thereof.



**FIG. 5**

## Description

**[0001]** The invention relates to a lightning protection apparatus for a longitudinal member in particular a rotor blade of a wind turbine comprising an electrical conductor arranged along the length of the member. Moreover, the invention is also directed to a method for providing and renewing a lightning protection apparatus and to a longitudinal member, in particular a rotor blade for a wind turbine provided with a lightning protection apparatus.

**[0002]** Examples of such elongated members which typically have low electrical conductivity, are in contact with the ground, and consequently need to be protected from damage by lightning strike are flagpoles, tall buildings etc. The natural events of lightnings have been investigated in detail. About one third of the lightning strokes are so-called "forked" lightnings, cloud-to-ground, or "ground strokes" which are the ones that are most relevant for damages. These strokes can have positive and negative polarity which is varying from area to area and also depends on the intensity of the stroke. It has been found that about 49 % of these strokes have currents up to 40.000 Amps, 49 % between 40.000 and 200.000 Amps and only 2 % above 200.000 Amps. The voltages can vary between 100.000 volts and 2 million volts. This is the typical basis for tests conducted at laboratories. Protection is widely reported to be appropriate if a system can withstand currents up to 200.000 Amps. For example, on buildings it is known to arrange an electrical conductor in the form of a steel wire with a diameter of about 1 cm to conduct the electrical charges of the lightning into the ground.

**[0003]** One area where lightning strike protection is particularly important are rotor blades on wind power stations. Such wind turbines are installed to a growing extent for purposes such as generating electrical power, typically in areas in which the weather conditions ensure streams of wind over significant periods of time during the year combined with dramatic changes in structure heights on ground, arising 40 to 50 meters. The most frequent damages occurring with the rotor blades of these wind turbines are caused by electrical lightnings.

**[0004]** Typically the wind turbines are provided with several rotor blades which are generally hit by a lightning strike when they are in the corresponding upper position. Most likely this occurs at the tips of the blades which are typically made of a non-conductive plastic material, especially glass-fiber reinforced plastic (GRP). The strokes can damage these blades so seriously that they either have to undergo an expensive repair or in the worst case that they have to be completely replaced. Lightning strokes affect the entire construction of the wind turbine and the rotor blades are the second most likely items to be damaged after the electronic system.

**[0005]** Due to the increasing number and size of these wind turbines this has become a significant factor.

In the meantime solutions have been identified which to some extent provide a protection against lightning strikes using the conventionally known internal techniques to guide the electrical charges to the ground.

**[0006]** Solutions described in the prior art provide an electrical conductor which conducts the electrical charge of the lightning to the ground. The electrical conductor has to have a cross section large enough to withstand a current up to 200.000 Amps.

**[0007]** DE-A-44 36 197 (Wobben) describes a wind power station for the generation of electrical energy in which the blades at their two longitudinal sides are provided with conductive components which towards the hub are arranged in a manner so that continuously a small air gap is created between parts of the conductive components and an arrangement in the tower-type stand that allows a direct electrical connection to the ground. In case of a lightning strike the charges are transferred over this spark gap or discharging distance to the ground. The conductive portions of the blades have cross sections in the order of 100 sq.mm.

**[0008]** WO-A-96/07825 (Bonus Energy) relates to a similar approach. One or several conductive rods project from the tip of the rotor blade which are electrically connected to a solid conductor which is arranged inside the blade and which can carry the charges from a lightning strike to a spark gap arranged near the hub. It is particularly referred to the fact that the internal arrangement of the conductor inside the blades prevents problems of using external conductors as those need to have a high cross section and could cause noise and reduce the efficiency. Such a construction, although quite effective in preventing damage caused by lightning strikes, is also quite expensive to manufacture. It is not possible to retrofit existing systems with this apparatus.

**[0009]** EP-A-0 707 145 and EP-A-0 718 495 (Autoflug Energietechnik GmbH) refer to a lightning protection apparatus in which several longitudinal stripes made of copper mesh are arranged at the rotor blades. The longitudinal stripes are connected between each other by additional stripes perpendicularly arranged to the main ones. The purpose of this arrangement is to reduce the current density as much as possible while conducting the charge of the lightning strike. In order to achieve the desired reduction in current density, the cross sections of the wires forming the mesh are added up to produce a large cross section which can safely conduct the charge to the ground. No reference is made to the way of fixing the mesh to the blades.

**[0010]** Generally, there are conflicting demands in the design of the conductor. Conductors of large cross section are desirable to conduct the lightning safely. On the other hand, bulky constructions are to be avoided, especially on rotor blades, where the aerodynamic properties are important. Additionally, although it is desirable to include the electrical conductor inside the longitudinal member, this is quite complicated and

expensive. Especially, the lightning protection apparatus of the prior art are not adapted to be used to retrofit existing members at site, like rotor blades on existing wind turbines.

**[0011]** It is therefore the object of the invention to improve the concept of an electrical conductor arranged along the length of the member to provide a lightweight non-reflective lightning protection apparatus which is inexpensive and simple to affix to the member, yet effective in preventing damage caused by lightning strike.

**[0012]** This object is achieved by the lightning protection apparatus according to claim 1 or 16, respectively, the tape used in the way described in claim 17 or 18, respectively. Dependent claims relate to preferred embodiments.

**[0013]** The lightning protection apparatus according to claim 1 is characterized in that the conductor is an electrically conductive layer of a tape, having also an adhesive layer, which tape is attached to the outer surface along the length of the longitudinal member by means of the adhesive layer.

**[0014]** Instead of using known constructions of lightning protection equipment, which have to be fixed to the longitudinal member by suitable holding mechanisms, the lightning protection apparatus according to the invention is of a much more simple, yet effective structure which offers substantial advantages over the prior art. In the invention, lightning protection is applied externally, i.e. to the outer surface of the longitudinal member in order to leave out the rise of air expansion cracks in hollow constructions caused by the high temperature evaporation of present humidity when a lightning is guided internally through the member. According to the invention, a tape is used which contains a layer of electrically conductive material. There are numerous ways in which such a conductive layer can be built, which will be discussed further on. The tape also comprises an adhesive layer. The type of adhesive used depends on the environmental conditions of the place where the tape is used. In particular, an electrically conductive adhesive can be used.

**[0015]** Any longitudinal member, which is in contact to the ground directly or via additional members and therefore could be potentially damaged by a lightning striking the member, can be protected by the lightning protection apparatus according to the invention. The tape can be easily applied to the outer surface of the member and remains attached to the member by means of the adhesive layer. There are no modifications necessary to the member, such as holes or grooves in which the conductor is guided. There are also no further means necessary for fixing the tape to the member, such as screws, holders etc. The tape has the shape of a flat, longitudinally extending strip and can be applied at any smooth surface of the member.

**[0016]** Such tapes already exist. For example, the Scotch (TM) 1190 metalized shielding tape with conductive adhesive, available from 3M Company, St. Paul,

Minnesota, USA, originally intended to be used for EMI-shielding, can be used to provide lightning protection to the longitudinal member.

**[0017]** As an alternative, according to the invention, the lightning protection apparatus comprises a film of a material layer which can be adhered to an element to be protected by means of a layer of adhesive material which is electrically conductive. Accordingly, the conductive layer of the tape according to this alternative of the invention is provided as an adhesive layer. The material layer of the film serves as a support or backing layer for the adhesive material as well as a cover layer for protecting the adhesive layer.

**[0018]** The new apparatus provides significant advantages over the prior art. Although it is common to provide an electrical conductor by which the electrical charges of the lightning are led to the ground, such a conductor has never before been provided in shape of a conductive layer of a tape adhered to an element to be protected.

**[0019]** Although US-A-4,352,142 (Boeing) describes a lightning protection system for an aircraft including layers of aluminum foil placed onto the non-conductive structure of aircraft components, this construction is not comparable to the invention. By principle, the potential differences occurring at a lightning strike on a plane are considerably less than on a grounded configuration, so that the aircraft being in the air is subjected to lower currents as a consequence of the lower potential differences. Also, the problem posed here is completely different: while for a member, connected to the ground, which is struck at its tip, a way has to be provided to safely guide the lightning charges into the ground, in an aircraft, the main objective is to avoid damages from thermal and right-angle effects of the lightning at the point where it strikes the aircraft component. A multilayer laminate covering the whole surface of an aircraft wing, is not comparable to an adhesive tape according to the invention, which is only applied on a part of the surface. The tape used according to the invention does not cover the member, but only provides a path for the electrical charges along the length of the member.

**[0020]** In EP-A-0 776 623 (Eurocopter, France) and US-A-3,923,421 (United Technologies Corporation) lightning protection apparatus are described for helicopter blades, where also the requirements are in principle different from constructions on the ground as the potential differences are in principle smaller.

**[0021]** The lightning protection apparatus according to the invention is particularly useful on the rotor blade of a wind turbine. It is very easy to retrofit existing, formerly unprotected rotor blades with the tape according to the invention. The tape, because of its flat and conformable structure and good adhesion to the surface of the rotor blade, can be arranged so that it does not affect the aerodynamic properties of the rotor blade substantially. The tape with the electrically conductive

layer is applied along the length of the rotor blade, preferably covering the leading edge. Electrical charges from a lightning striking the tip of the blade are guided by the electrically conductive layer to the hub, where the rotor blade is fixed. Conventionally known systems including a spark gap (e.g. DE-A-44 36 197 or WO-A-96/07825) can be employed to further guide the electrical charges to the ground. The invention is primarily concerned with the protection of longitudinal members, such as the rotor blades, so that known protection systems for e.g. the turbine can easily be used in combination with the lightning protection system according to the invention.

**[0022]** The electrically conductive layer can provide a cross section large enough to conduct currents of up to 200.000 Amps. According to a preferred embodiment of the invention, however, the conductive layer provides such a configuration of its geometry and electrical properties, that in the event of a lightning strike the electrically conductive layer guides the lightning charges along its surface, while at least a part of the electrically conductive layer evaporates.

**[0023]** This is a new concept of providing lightning protection to members connected to the ground. While prior art concepts invariably aim at conducting the electrical charges through a conductor with a cross sectional area large enough to conduct the charges, the configuration according to the preferred embodiment provides a conductive layer that is quite thin and therefore by comparison only provides a small cross section, but a large surface. As a lightning strikes the member, it is attracted by the electrically conductive layer because of the conductivity thereof.

**[0024]** A thin layer of conductive material does not provide enough cross section to effectively conduct the charges. This is why the conductive layer evaporates as a part of the electrical charges pass through it. Experiments have shown, that the charges nevertheless follow the path of the electrically conductive layer. The lightning is therefore guided along the surface of the tape and follows the tape along the length of the longitudinal member. Although some conductive layer of the tape is destroyed, the surface of the longitudinal member to which the tape is attached remains undamaged.

**[0025]** The flat structure provided by the adhesive layer is very advantageous for this guiding effect. Although already a very thin copper wire could achieve a guiding effect, lightning tends to jump statistically while it is guided along the longitudinal member. On the surface of a flat structure such as the adhesive layer of the tape, the electrical charges still jump certain distances, but do not leave the path prescribed by the tape and are thus guided by the tape along the surface of the longitudinal member.

**[0026]** Because of the statistical nature of lightning strikes, it is very hard to give exact limits under which the above-described surface-guiding effect is achieved. For lightnings of low intensity, e.g. 40.000 Amps, even a

thin conductive layer may still be able to conduct the electrical charges without the tape being destroyed. Some lightning strikes, on the other hand, may be of such high a voltage that even the formerly known structures of the prior art would, at least in part, evaporate while conducting the lightning to the ground.

**[0027]** While therefore it is hard to exactly define the geometry and electrical properties necessary to always achieve the above-mentioned surface guiding effect, the new concept provides a significant new approach to the design of a conductor, since it no longer has to be designed to be able to withstand the current generated by a lightning strike and conduct the electrical charges. The geometry of the conductor may thus vary considerably.

**[0028]** Configurations found useful in experiments are a thickness of the conductive layer of 0.05 to 0.5 mm. Especially a thickness of the conductive layer of about 0.1 mm is preferred. For the width of the conductive layer, a strip of 1 to 10 cm extending along the length of the tape has been found useful. Especially preferred is a strip of a width of about 3 to 7 cm and, in particular, of about 4 cm.

**[0029]** After a lightning strike, which is guided along the longitudinal member by the electrically conductive layer, thereby destroying at least parts of the layer, the tape can easily be repaired or the remaining parts of the tape can be removed to replace them by new tape.

**[0030]** It is an advantageous property of the tape that it is flexible and therefore able to adjust to deformations of the longitudinal member, such as bending of the rotor blades caused by wind. For achieving a flexible tape, the electrically conductive layer of the tape can be formed as a mesh of thin metal wires. It is also possible to form the electrically conductive layer of the tape as a film of metal material. Also suitable constructions comprise electrically conductive layers comprising metal particles dispersed in a polymer layer.

**[0031]** For protection of longitudinal members disposed under severe environmental conditions and thus subjected e.g. to erosion by wind or particles, such as sand, a preferred embodiment comprises an abrasion-resistant protective tape with an adhesive layer, the protective tape covering the tape comprising the electrically conductive layer. After applying the first tape, comprising the conductive layer, to the surface of the longitudinal member, a second tape is attached on top of the first tape. The second tape is an abrasion-resistant tape, which covers the first tape and protects it from wear and damage due to environmental influences, such as erosion by particles.

**[0032]** Instead of using two tapes which are applied one on top of the other, it is also possible to provide a laminated tape already consisting of an adhesive layer, an electrically conductive layer and an abrasion-resistant protective layer. Preferably, the abrasion-resistant protective layer (or tape) is wider than the strip of electrically conductive material and overlaps the strip along

both of its side edges.

**[0033]** The protective layer (if one tape comprising all three layers is used) or the protective tape (if two tapes are used one on top of the other) thus provides excellent protection of the strip of electrically conductive material and also serves to firmly fix the strip of electrically conductive material to the surface of the elongated member. In the case of the rotor blade of a wind turbine, the protective tape or a layer can also protect the rotor blade itself from wear due to environmental influences. Especially when applied to the leading edge of the rotor blade, the abrasion-resistant tape or layer can effectively protect the rotor blade from erosion and abrasion caused by particles in the air. Leading edge erosion damage on wind turbine blades has shown a loss of production of 25 %.

**[0034]** One example for a protective tape which could be used is 8681 HS polyurethane protective tape available from 3M Company, St. Paul, Minnesota, USA, which is an abrasion and erosion resistant polyurethane tape with an acrylic adhesive mainly used on helicopter rotor blades. This tape has a total thickness of about 0.36 mm. Generally, a protective layer out of polyurethane material with a thickness in the range of 0.2 mm to 1 mm has been found useful. Preferably, the protective layer is of a thickness of about 0.3 mm.

**[0035]** The electrically conductive layer preferably is of metal material, forming a strip extending along the length of the tape. The strip has a width which should be large enough to ensure that the lightning charges guided on the surface do not deviate from the path prescribed by the tape when they statistically jump. The electrically conductive layer should be of a conductivity several orders of magnitude higher than the electrical conductivity of the longitudinal member, since lightning is always attracted towards bodies of higher conductivity. Thus, by applying a strip of metal material on a non-conductive longitudinal member such as a fiber glass rotor blade, the lightning can be effectively guided. Although an electrically conductive layer of copper material is preferred, other conductive materials such as aluminum, steel or any other electrically conductive material known to the person skilled in the art could be used. It has been found useful, that the conductive layer has a surface resistance of less than 0.1  $\Omega$  per square.

**[0036]** Some of the rotor blades on wind turbines are provided with a so-called "tip brake". In this case, a rotor blade is divided up in sections which are mechanically separated from each other and can be rotated around an axis in the lengthwise direction of the rotor blade. On these rotor blades, it is not possible to apply the tape without any interruption, because this would prevent the rotating movement of the sections against each other. In this case, it has been found useful to divide the tape in two sections, each attached to one section of the rotor blade, which tape sections are separated from each other forming a gap at the joint connecting the sections of the rotor blade. Usually the tape

is applied in a way such that when the sections of the rotor blade are in a normal position, the ends of the tape sections are in close proximity to each other. Thus, there is only a small gap and a lightning guided by the electrically conductive layer of the tape can easily jump the distance of gap and is thus safely led along both sections of the tape.

**[0037]** When the sections of the rotor blade are rotated against each other to form, e.g., a 45° angle, the ends of the tape sections form a larger gap. It has been found, though, that the electrical charges also jump this larger distance.

**[0038]** As mentioned above, according to an alternative of the present invention, the conductive layer of the tape is its adhesive layer which in this case is electrically conductive. All what is said above with regard to the conductive layer of the tape also applies for a tape in which the adhesive layer is electrically conductive.

**[0039]** By means of the invention, it is possible to easily provide lightning protection on a longitudinal member. For performing this it is merely necessary

- to provide a tape comprising an electrically conductive layer and an adhesive layer and
- to apply the tape on the outer surface along the length of the longitudinal member, the adhesive layer sticking to the surface of the longitudinal member.

**[0040]** As an alternative, a lightning protection on a longitudinal member can be provided easily in that an adhesive tape is used comprising an electrically conductive adhesive layer adhered to the surface of the longitudinal member.

**[0041]** After a lightning strike was guided along the lightning protection tape applied to the longitudinal member, at least those portions of the tape (electrically conductive layer and/or electrically conductive adhesive) which are damaged due to the lightning strike can be easily removed and replaced by applying a new tape. Accordingly, the lightning protection of the invention is designed for as to be damaged when a lightning strike is guided resulting in preventing the longitudinal member from being damaged.

**[0042]** Preferably, after a lightning strike was applied to the tape, all of the tape irrespective of being damaged or not is removed from the longitudinal member so as to apply new tape to the outer surface of the longitudinal member.

**[0043]** The tape most preferably is provided as a roll from which the tape prior to application to the longitudinal member can be easily wound up.

**[0044]** Preferred embodiments of the present invention will be described in detail with reference to the drawings, where throughout the Figures like numerals refer to like parts. In the Figures,

Fig. 1 shows a perspective view of a wind turbine

with a turbine comprising a rotor with three rotor blades,

Fig. 2 shows a view of the cross section taken along line II-II in Fig. 1,

Fig. 3 shows a cross sectional view of a tape applied to a rotor blade according to a first embodiment of the invention,

Fig. 4 shows a cross sectional view of a tape applied to a rotor blade according to a second embodiment of the invention,

Fig. 5 shows a perspective view of a rotor blade of a turbine being struck by lightning.

[0045] In Fig. 1 is shown a wind power station 10 including a stand 12 which carries a turbine 14 at its top. On the turbine 14 is rotatably mounted a rotor 16 comprising three rotor blades 18 mounted on a hub 20. This configuration of a wind power station 10 is a typical configuration which is shown here only as an example used for illustration purposes. The specifics regarding the stand 12, the turbine 14 and the rotor 16 will not be discussed here, but are known to the skilled person.

[0046] Generally, the tower-type stand 12 is grounded, i.e. there is an electrical conductor of large cross section arranged along its length or the stand itself is made of conductive material, such as metal. The hub 20 consists of metal material and in normal operation is electrically isolated from the ground. There are, however, provisions to conduct electrical charges resulting from a lightning strike from the hub 20 over the stand 12 into the ground. Such provisions include configurations such as spark gaps described inter alia in DE-A-44 36 197 or EP-A-0 707 145. The apparatus described here is not a turbine protection system, but a protection system for longitudinal members such as the rotor blades 18. Therefore, the following description will only be concerned with a single rotor blade and way of applying an electrical conductor to such a rotor blade 18 to guide electrical charges toward the hub 20.

[0047] The rotor blade 18 is made of glass-fiber reinforced plastic (GRP), a non-conductive plastic material. The total length of the rotor blade 18 is 25 m. The rotor blade 18 here serves as an example for a longitudinal member on which lightning protection has to be provided.

[0048] In Fig. 2, which shows a cross sectional view of the rotor blade 18, is shown a tape 22 applied to the outer surface 32 of the rotor blade 18 along the leading edge 24, i.e. the edge which usually faces in the wind direction.

[0049] The tape 22 is an adhesive tape with a layered structure, which is shown in detail in Fig. 3. The tape 22 consists of an adhesive layer 26, an electrically conductive layer 28 and protective layer 30. The tape 22

sticks to the outer surface 32 of the rotor blade 18 by means of the adhesive layer 26. The adhesive is an acrylic adhesive which ensures excellent bond strength to the surface 32. The acrylic adhesive is a long-aging, solvent resistant, pressure sensitive adhesive which provides good peel strength.

[0050] The electrically conductive layer 28 is formed as a mesh of very thin copper wires. This layer is thus flexible and does not break when the tape 22 is bent or stretched (e.g. during movement of the rotor blade 18 or when the tape 22 is wound in a roll). The thickness of the conductive layer 26 is preferably of about 0.1 mm. In different embodiments, the thickness may vary considerably for example in the range of about 0.05 to 0.5 mm. The surface resistivity of the conductive layer in the preferred embodiment is below 0.1  $\Omega$  per square. In principal, every conductive tape with a surface resistivity in the same order of magnitude can be used. It is, however, important that the conductivity of the conductive tape is significantly larger than the conductivity of the longitudinal member.

[0051] The electrically conductive layer 28 forms a strip of constant width along the length of the rotor blade 18. The width of this strip is 38 mm in a preferred embodiment. It has been proven in tests that even a width of 1 cm or even less could be sufficient to guide the electrical charges, but as the width of the strip gets smaller, the danger of the electrical charges leaving the path prescribed by the tape is increased. The upper limit for the width of the strip is mainly determined with consideration to cost and handling. Strips preferably up to a width of 10 cm can be used.

[0052] Generally, thickness, width and conductivity of the electrically conductive layer should be chosen and proved in tests to ensure that for the majority of lightning strikes (e.g., below 200 kA) are safely guided to ground, so that the rotor blade remains undamaged.

[0053] The protective layer 30 is an abrasion resistant layer of polyurethane material. It has a thickness of 0.36 mm and is considerably wider than the electrically conductive layer 28, which it overlaps along both of its side edges. The protective layer 30 is 30 cm wide. It is laminated to the electrically conductive layer 28.

[0054] Fig. 4 shows an alternative embodiment, in which two tapes 22a, 22b are applied on top of each other. The tape 22b is Scotch 1190 metalized fabric shielding tape available from 3M Company, St. Paul, Minnesota, USA, which is sold as a tape for EMI-shielding. The conductive layer 28 of the conductive tape 22b consists of a metalized fabric, which is coated with a conductive acrylic adhesive forming an adhesive layer 26b. This material provides a high level of conductivity in an extremely strong yet lightweight and conformable material. Protective tape 22a is 8681 HS polyurethane protective tape available from 3M Company, St. Paul, Minnesota, USA, consisting of exceptionally tough abrasion and erosion resistant polyurethane. The total thickness of the protective tape 22a is 0.36 mm. Tape

22a includes an adhesive layer 26a by means of which protective tape 22a sticks both to the surface 32 of the rotor blade 18 and the back of tape 22b.

**[0055]** Tapes 22a and 22b each are delivered in rolls with a release liner covering the adhesive layers. First, conductive tape 22b is applied to the surface 32 of the rotor blade 18 along the leading edge 24 of the rotor blade 18 by removing the release liner and applying tape 22b to the surface 32. Then, protective tape 22a is applied on top of tape 22b, covering both tape 22b and the leading edge 24 of the surface 32 of rotor blade 18.

**[0056]** Protective tape 22a or protective layer 30 of tape 22 serve to protect the surface 32 of rotor blade 18 against erosion caused by contact with particles transported in the air, such as sand. Protective layer 30 or protective tape 22a also help to firmly fix conductive layer 28 or conductive tape 22b on the leading edge 24 of the rotor blade 18.

**[0057]** Turning now to Fig. 5, there is shown rotor blade 18 in more detail. Rotor blade 18 consists of two sections, a hub section 36 and a tip section 34 which are connected by a joint 38, formed by an axis made of a carbon fiber material (not shown). At joint 38, the sections 34,36 can rotate against each other to form a so-called "tip brake", used to cause a slow-down or stall effect similar to that used in aircraft rotor blades. The sections 34,36 can be rotated at angles between 0° and 90°, where at 0° the position of tip section 34 is completely in line with the hub section 36, while at the 90° position the tip section 34 is an arrangement perpendicular to that of the hub section 36. The tape 22 consequently is divided into two sections 40,42, which are separated from each other such that their ends 44,46 form a gap 48. The width of the gap 48, i.e. the distance between the ends 44,46 of the tape sections 40,42, depends on the angle of rotation between the tip section 34 and the hub section 36 of the rotor blade 18. In the shown position of about 45° between the tip section 34 and the hub section 36, the width of the gap 48 is about 20 to 30 cm.

**[0058]** When the rotor blade 18 is hit by a lightning strike, this usually occurs at the tip of the rotor blade 18 as shown in Fig. 5. At the tip, tape 22 forms a sharp edge, which attracts the lightning and immediately leads it toward tape 22. This is because the conductive layer 28 provides good electrical conductivity compared to the material of rotor blade 18. Edges such as the one formed at the end of tape 22 at the tip of rotor blade 18 are also known to attract lightning. The electrical charges of the lightning cause the creation of an electrical discharge along the entire tape similar to the one in a fluorescent lamp. This means that the electrical charges are guided to the ground in the air above the length of tape 22 through this discharge and that the tape 22 as such essentially acts as a guiding means protecting the plastic material of the rotor blade 18 upon which it is placed. This means, that the tape 22 as such only carries a very small fraction of the electrical charge

as it evaporates. The path of the electrical charges along the surface of tape 22 is not straight. The electrical discharge, as can be seen on photographs taken during tests, statistically jumps at several points on the surface of tape 22. This is shown in Fig. 5. The conductive layer 28 of tape 22 is wide enough to ensure that the electrical charges do not deviate from the path prescribed by tape 22.

**[0059]** At the gap 48 between the ends 44,46 of the sections 40,42 of the tape, the charges also jump the distance of about 20 to 30 cm safely, without causing damage to either of the sections 34,36 of the rotor blade 18. The electrical charges are eventually transported to hub 20, which over a device including a spark gap (not shown) carries the charges into the ground.

**[0060]** Typically, while most of the charge is carried to ground within a very short time below a fraction of a second, the tape 22 is ruptured in several places. This means that after a single lightning strike of high current, the tape 22 or portions of it is expected to be replaced. This, however, is not considered to be a substantial disadvantage, but should be seen as a major advantage as the repair of such a rotor blade 18, which has a tape 22 interrupted at some location, can be achieved easily by simply removing the tape 22 and replacing it by another one. Usually, this would require to clean the surface 32 of the rotor blade 18 prior to the application of the tape 22.

**[0061]** The following tests were conducted with the preferred embodiments. For a high amperage test, used to determine geometry and electrical properties needed, the test samples were prepared as follows:

**[0062]** Flat plates of the rotor blade material, such as glass-fiber reinforced plastic (GRP) of an extension of about 0.5 to 1 m or in the given example of 600 x 600 mm with a thickness of 3 mm are provided, and a tape construction is applied onto them. A conductive tape 22b as described above of a width of 38 mm is applied in the middle so that a distance of 180 mm is obtained towards one edge of the plate. The other end is arranged so that a connection to ground can be established. This relatively small strip is covered with a protective tape 22a as described above providing the abrasion resistance. In this specific configuration the extension of this tape 22a is significantly larger than that of the conductive tape 22b.

**[0063]** At the end of the conductive tape 22b which is 180 mm apart from the edge, an electrode is placed relatively close to the end of this tape 22b so that a spark can be generated. A high voltage is applied and the resulting discharge current are measured so that currents in the order of 200.000 Amps are obtained with an action integral of about  $2 \times 10^6 \text{ A}^2\text{s}$ . This corresponds to a transmitted charge in the order of 120 Coulombs which is to be considered as a severe strike. Configurations of the described type show typically an initial resistance in the order of a few tenths of ohms/m sufficient to ensure the appropriate guidance of the lightning

strike.

**[0064]** When subjecting this configuration to a lightning strike the decisive feature is whether or not the blade material as such will remain completely undamaged. As described above, a discharge is obtained. Photographs have shown what is essentially depicted in Fig. 5, namely that a discharge occurs which is capable of carrying the total charge of about 120 Coulombs which occurs in the air above the thin layer 28 of conductive material which is even covered with an insulating material. Furthermore typically the conductive tape 22b does not survive this test. It is ruptured at some position and together with the abrasion resistant cover tape 22a it is more or less blasted away from the surface 32. However, when using an appropriate configuration of tapes 22a,22b no damage is observed with the blade material. This test gives a means to identify whether a geometrical configuration and the appropriate selection of the electrical properties of the tape material fulfills the requirement to provide protection against lightning.

**[0065]** While the above-described preliminary test method appears to be appropriate for a preselection of the tape material and construction, it may be desirable to subject a selected configuration to a test which is as close as possible to the real use. Such a high voltage test is described in the following:

**[0066]** Tapes 22a,22b as described above are applied onto the leading edge of a rotor blade 18 having a length of e.g. 5 to 6 m. This can, for example, be achieved by applying subsequently the above-described 3M Tape 1190 having the electrical conductivity and covering this tape 22b with the abrasion resistant polyurethane tape PPT 8681 HS. For a good preparation it might be advantageous to clean the surface of the rotor blade with MEK/acetone to ensure a good adhesion. If the adhesion is low which is typical for GRP, adhesion promoter such as tape adhesion promoter 86 from 3M can be used, at least at the tape edges, in order to improve durability. It is preferable to determine the resistance which over lengths of several meters should be in order of several ohms. In case of a tip brake the tape sections 40,42 should be applied independently on both the tip section 34 and the hub section 36 so that in the zero degree position of the tip section 34 the ends 44,46 of the tape sections 40,42 are relatively close to each other. As the results show, the distance is not very critical. The end of the tape 22 near the hub 20 is grounded and the entire rotor blade 18 is then subjected to a high-voltage test. Electrodes are positioned near the tip of rotor blade 18. The electrodes are spheres which are electrically connected to an impulse generator.

**[0067]** In the test, five different configurations of the sphere are used, one direction away from this tip and one configuration about 2.5 m downwards in the direction to the hub 20 having a distance of 1 m with respect to the trailing edge. In two further positions, the sphere was placed beneath the plane given by the blade 18

which is supposed to be the worst case as the electrode is arranged opposite to the side where the lightning protection tape 22 has been applied.

**[0068]** The system is then subjected to a lightning strike by applying a voltage of 1.5 MV which for instance can be obtained by an impulse generator having several stages of 200 kV each. The system allows a measurement of the wave form and the wave could be arranged so that for instance a rise time of 60 micro seconds and the half value after 2500 micro seconds is obtained. The generator is then subjected to both negative and positive polarity pulses. With the above-described tape configuration and the use of GRP rotor blades a 100 % success rate for negative pulses and a 92 % success rate for positive pulses has been observed. A success in this case means that the tape 22 is successful in conducting the lightning and that accordingly no damage of the rotor blade 18 is observed. In case of the use of a tip brake the rate of success depends on the opening angle. If the tip is opened at an angle of 45 degrees, the success rate still stays at 100 % for the negative polarity although an air gap of e.g. 180 mm has to be passed. For the positive polarity the success rate is decreased substantially. This can be improved by providing different geometrical configurations at the ends 44,46 of the tape sections 40,42. It has to be taken care, however, that the carbon fiber axis is not affected by the lightning strike.

**[0069]** In all cases a rupture of the tape 22 occurs as described in the preliminary test method. It is, however, relatively easy to remove the destroyed tape portions and to replace them by a new tape configuration.

**[0070]** Further to the electrical testing a vibration fatigue test can be conducted, in which the system is also submitted to a mechanical test for a rotor blade 18. This is typically a vibration of a 25 m blade 18 with a frequency of 3 Hz for one month continuously which would be equivalent to a life time of the blade of 20 years.

**[0071]** With the above-described tape configuration applied to a 25 m GRP blade no tape lift off was observed after 7 million vibrations.

## Claims

1. Lightning protection apparatus for a longitudinal member, in particular a rotor blade of a wind turbine, comprising

- an electrical conductor (28) arranged along the length of the member (18),  
**characterized in that**
- said conductor (28) is an electrically conductive layer (28) of a tape (22,22b) having also an adhesive layer (26,26b) for adhering said tape (22,22b) to the outer surface (32) of the longitudinal member (18) along the length thereof.



2. Lightning protection apparatus according to claim 1, characterized in that the electrically conductive layer (28) has such a geometry and electrical properties that it guides the lightning charges along its surface, while at least a part of the electrically conductive layer (28) evaporates. 5
3. Lightning protection apparatus according to claim 1 or 2, characterized in that the tape (22,22b) comprises an electrically conductive layer (28) formed as a strip having a width, the strip consisting of metal material and extending along the length of the tape (22,22b). 10
4. Lightning protection apparatus according to any one of claims 1 to 3, characterized in that the electrically conductive layer (28) of the tape (22,22b) is formed as a mesh or fabric of thin metal wires. 15
5. Lightning protection apparatus according to any one of claims 1 to 3, characterized in that the electrically conductive layer (28) of the tape (22,22b) is formed as a film of metal material or as a film comprising metal particles dispersed in a polymer layer. 20
6. Lightning protection apparatus according to any one of the preceding claims, characterized by an abrasion-resistant protective tape (22a) with an adhesive layer (26a), the protective tape (22a) covering the tape (22b) comprising the electrically conductive layer (28). 25
7. Lightning protection apparatus according to any one of the preceding claims, characterized in that the tape (22) further comprises an abrasion-resistant protective layer (30) covering the electrically conductive layer (28). 30
8. Lightning protection apparatus according to claim 6 or 7, characterized in that the protective layer (30) or the protective tape (22a) is wider than the strip of electrically conductive material (28) and overlaps the strip along both of its side edges. 35
9. Lightning protection apparatus according to any one of the preceding claims, characterized in that the conductivity of the electrically conductive layer (30) is several orders of magnitude higher than the electrical conductivity of the longitudinal member (18). 40
10. Lightning protection apparatus according to any one of the preceding claims, for a longitudinal member (18) having at least two sections (34,36) connected by a joint (38) characterized in that the tape (22,22b) consists of at least two sections (40,42) along the length of the elongated member (18), which sections (40,42) are separated from each other forming a gap (48) at the joint (38) connecting the sections (40,42) of the elongated member (18). 45
11. Lightning protection apparatus according to any one of the preceding claims, characterized in that the conductive layer (28) is of a thickness in the range of 0.05 to 0.5 mm, in particular of about 0.1 mm. 50
12. Lightning protection apparatus according to any one of claims 1 to 11, characterized in that the conductive layer (28) is as a strip extending along the length of the tape (22,22b) and having a width of 1 to 10 cm, in particular 3 to 7 cm and preferably about 4 cm. 55
13. Lightning protection apparatus according to one or more of the preceding claims, characterized in that the conductive layer (28) has a surface resistance of less than 0.1 Ohm/square and/or the protective layer (30) is a polyurethane layer of a thickness in the range of 0.2 to 1 mm, in particular of about 0.3 mm.
14. Lightning protection apparatus according to one or more of the preceding claims, characterized in that the electrically conductive layer (28) consists of copper material.
15. Lightning protection apparatus according to any one of claims 1 to 14, characterized in that the adhesive layer (26,26b) is electrically conductive.
16. Lightning protection apparatus for a longitudinal member, in particular a rotor blade of a wind turbine, comprising
  - an electrical conductor (28) arranged along the length of the member (18),
  - characterized in that**
  - said conductor comprises a material layer and an adhesive layer for adhering the film layer to the outer surface (32) of the longitudinal member (18) along the length thereof and
  - said adhesive layer is electrically conductive.
17. Use of a tape for providing lightning protection to a longitudinal member (18), the tape (22,22b) comprising a layer of electrically conductive material (28) and a layer of adhesive (26,26b), wherein the tape (22,22b) can be applied to the outer surface (32) along the length of the member (18) so as to stick to the member (18) by means of the adhesive layer (26,26b).
18. Use of a tape for providing lightning protection to a longitudinal member (18), the tape comprising a material layer and an adhesive layer which is elec-

trically conductive, wherein the tape can applied to the outer surface along the length of the member so as to stick to the member by means of the adhesive layer.

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19. Use of a tape according to claim 17 or 18, characterized in that the tape is used to form a lightning protection apparatus according to one or more of claims 1 to 16.

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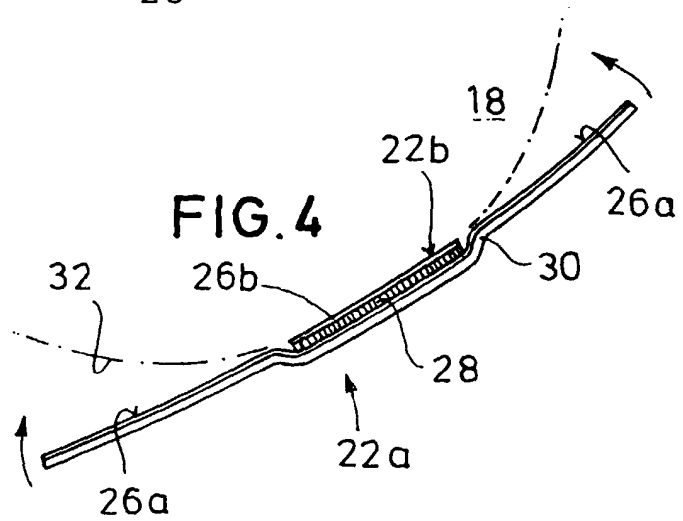
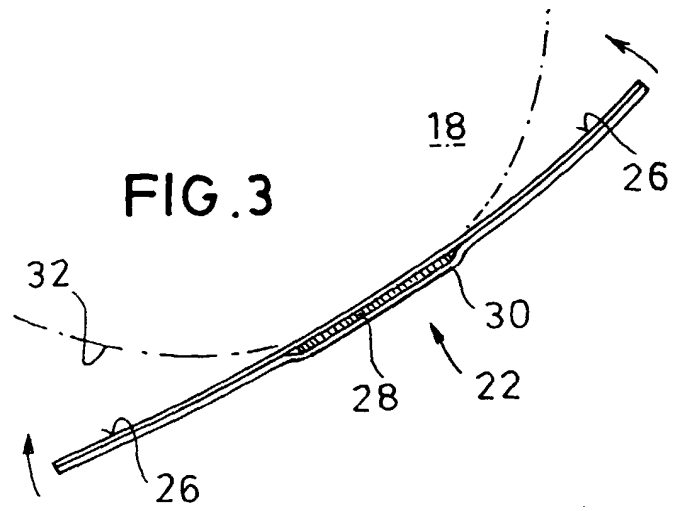
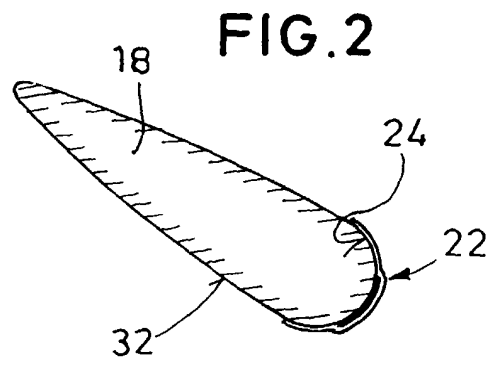
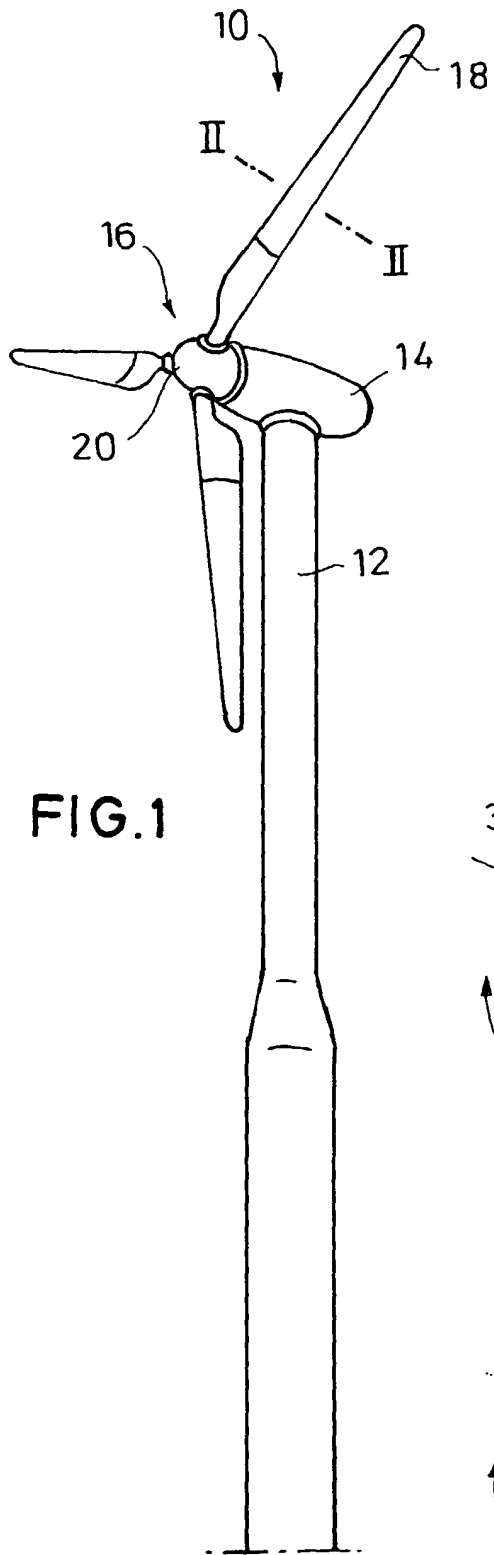
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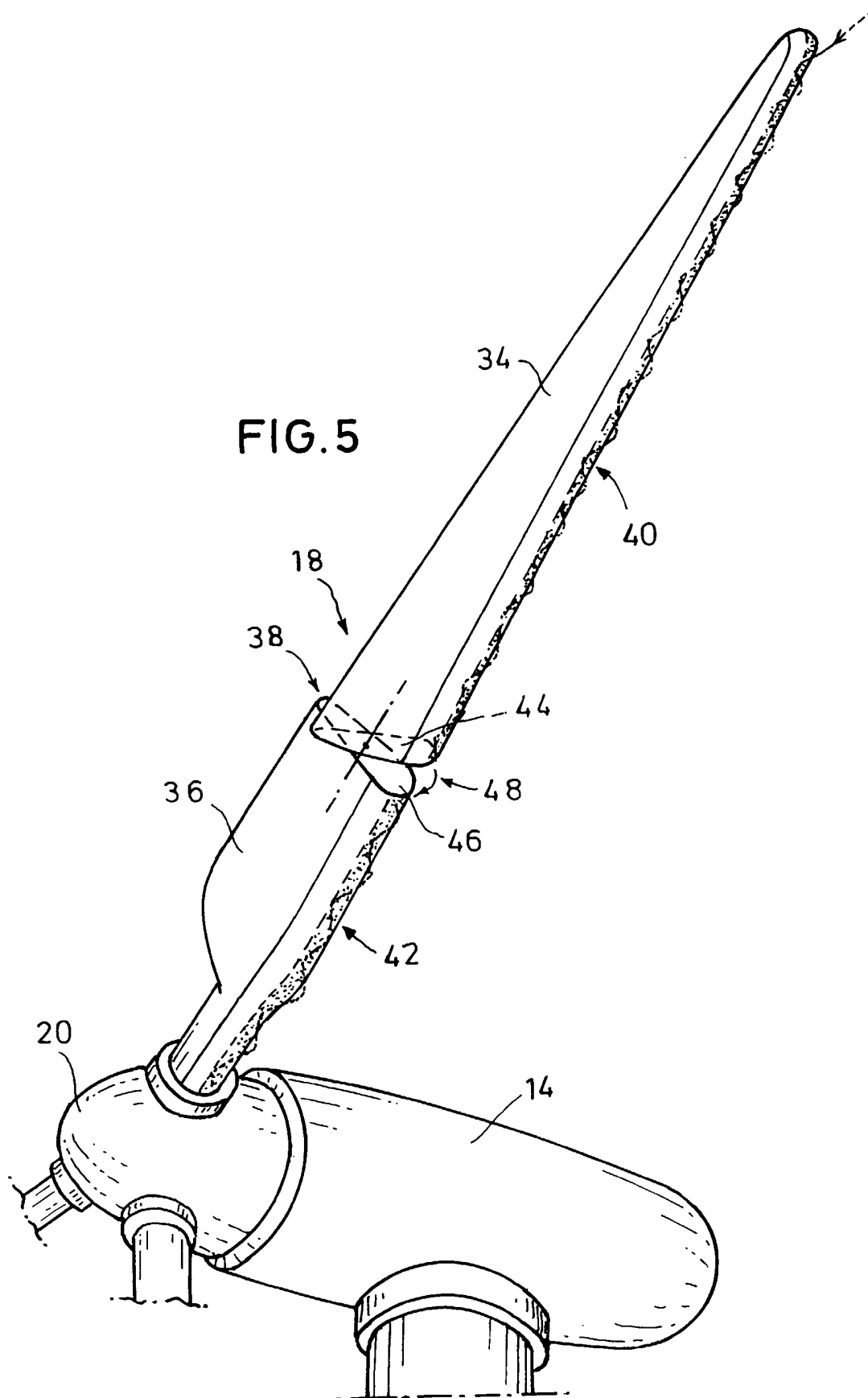
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# EUROPEAN SEARCH REPORT

Application Number  
EP 98 12 3733

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	US 2 982 494 A (AMASON) 2 May 1961  * the whole document *	1-3,5-7, 11,12, 17,19	H02G13/00 F03D11/00
X	US 5 841 066 A (BOCHERENS ERIC) 24 November 1998	17,18	
Y	* the whole document *	1	
A		2,3,5,6, 10,16	
Y	DE 197 48 716 C (AERODYN ENGINEERING GMBH) 12 November 1998	1	
A	* column 2, line 55 - line 62; figure 1 *	3,9,16	
D,A	EP 0 707 145 A (AUTOFLUG ENERGIETECH GMBH) 17 April 1996 * column 5, line 9 - line 29; claims 1-5; figures 1,2,4 *	1,4,10, 14,16	
D,A	EP 0 718 495 A (AUTOFLUG ENERGIETECH GMBH) 26 June 1996 * abstract; figure 1 *	1	TECHNICAL FIELDS SEARCHED (Int.Cl.6)  H02G F03D
The present search report has been drawn up for all claims			
Place of search <b>THE HAGUE</b>		Date of completion of the search <b>10 May 1999</b>	Examiner <b>Rieutort, A</b>
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons &amp; : member of the same patent family, corresponding document</p>			

EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT  
ON EUROPEAN PATENT APPLICATION NO.**

EP 98 12 3733

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on  
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**PUB-NO:** EP001011182A1  
**DOCUMENT-IDENTIFIER:** EP 1011182 A1  
**TITLE:** Lightning protection  
apparatus for a longitudinal  
member  
**PUBN-DATE:** June 21, 2000

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**APPL-NO:** EP98123733  
**APPL-DATE:** December 14, 1998

**PRIORITY-DATA:** EP98123733A (December 14, 1998)

**INT-CL (IPC):** H02G013/00 , F03D011/00

**EUR-CL (EPC):** F03D011/00 , H02G013/00

**ABSTRACT:**

CHG DATE=20000704 STATUS=O> The lightning  
protection apparatus for a longitudinal member  
(18) comprises an electrical conductor (28)

arranged along the length of the member (18). Said conductor (28) is an electrically conductive layer (28) of a tape (22,22b) having also an adhesive layer (26,26b) for adhering said tape (22,22b) to the outer surface (32) of the longitudinal member (18) along the length thereof. 